

# Planning and Initial Performance of a Cislunar Position, Navigation, and Timing Service

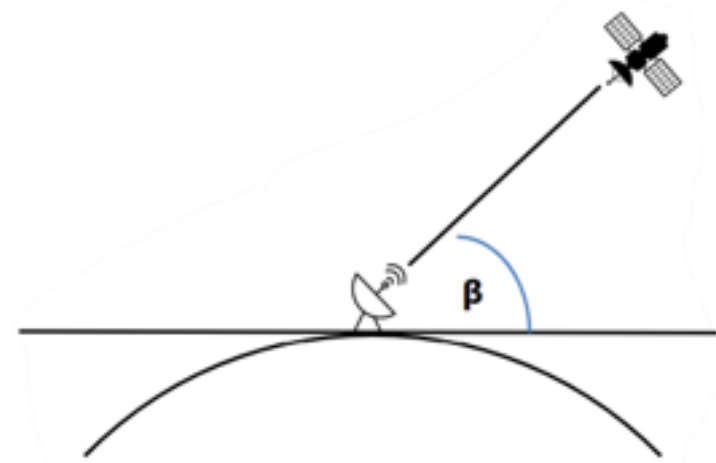
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## I. Motivation

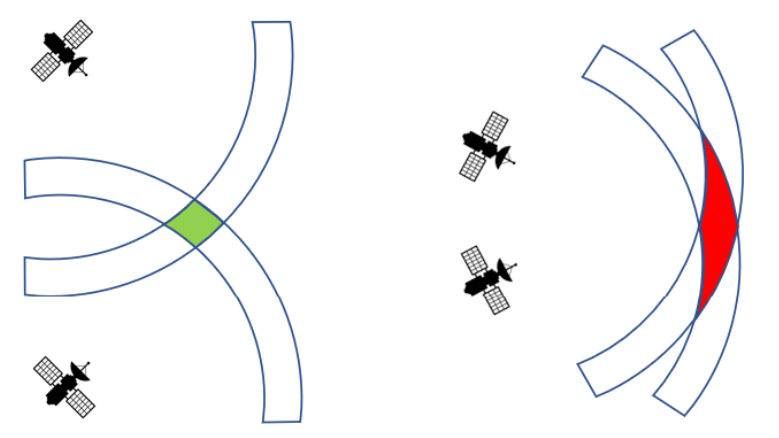
Cislunar space is becoming increasingly populated; current ground-based navigation methods – like the Deep Space Network – cannot keep up with demand. To meet this rising interest, several organizations are interested in establishing a dedicated position, navigation, and timing (PNT) service. Near-term missions display an increased interest in the lunar south pole; therefore, focus should be directed on a minimal near-term architecture capable of supporting scientific exploration. A standardized method is required to compare proposed constellations based on the achievable performance offered to users.

## II. Evaluation Metrics

- Number of satellites in contact with user**
  - Contact occurs when a satellite has a line of sight to the user and an elevation angle  $\geq 5^\circ$
- Coverage**
  - When the user has contact with 4+ satellites
- Gap Time**
  - Time without coverage
- Positional Dilution of Precision (PDOP)**
  - From the geometries of the orbits
- User Equivalent Range Error**
  - Error accumulated in reception of signal, including satellite clock error, orbit determination uncertainty, receiver noise, and signal multipath
- Navigation Analysis**
  - 24-hour performance of a ground station getting a position fix using a batch filter at  $-75^\circ$  latitude
  - 24-hour performance of a rover navigating using an extended Kalman filter (EKF) and accelerometer near the south pole



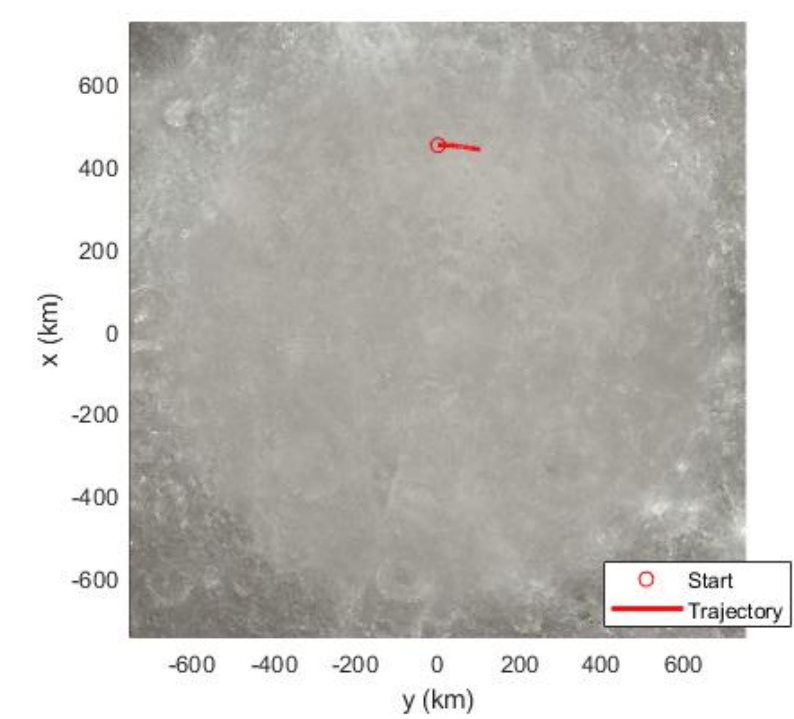
Satellite elevation angle



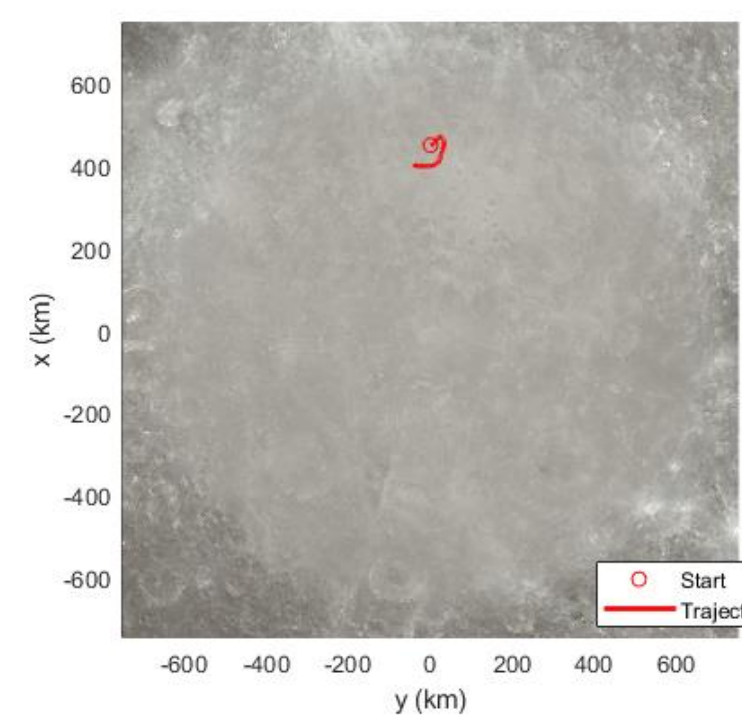
Dilution of precision due to satellite geometry

Source	95% RSS Position Error
Clock Model	8.994 m
OD Uncertainty	9.081 m
Receiver Noise	19.818 m
Multipath	1.960 m
Lunar Regolith	0 m
Signal-In-Space Errors	12.931 m
<b>Total</b>	<b>23.663 m</b>

Maximum of collected measurement error sources

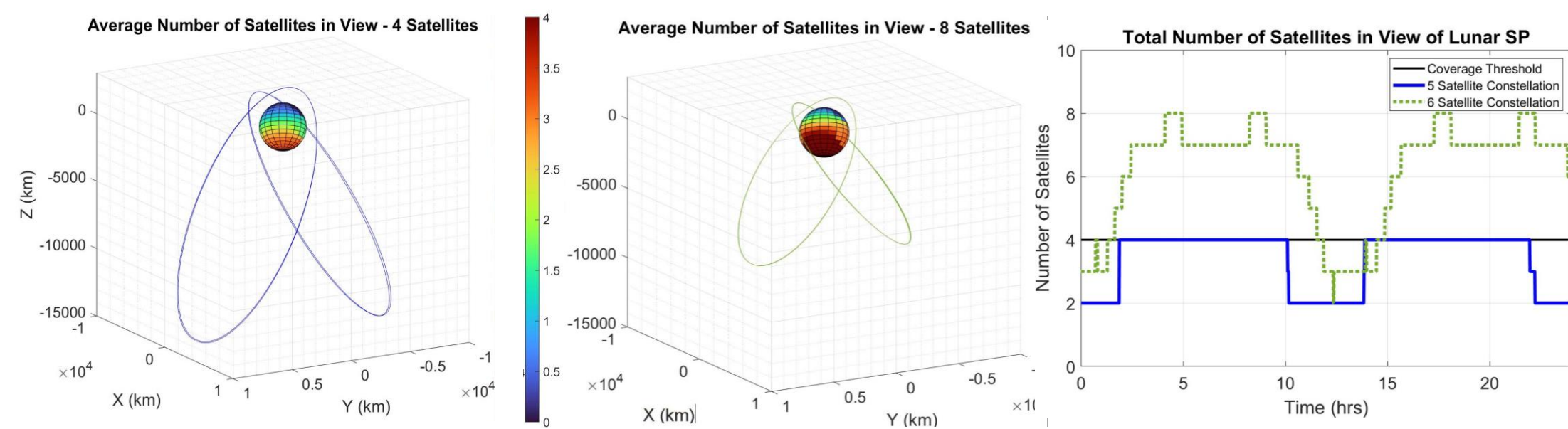


24-hour ground station trajectory at  $-75^\circ$  latitude

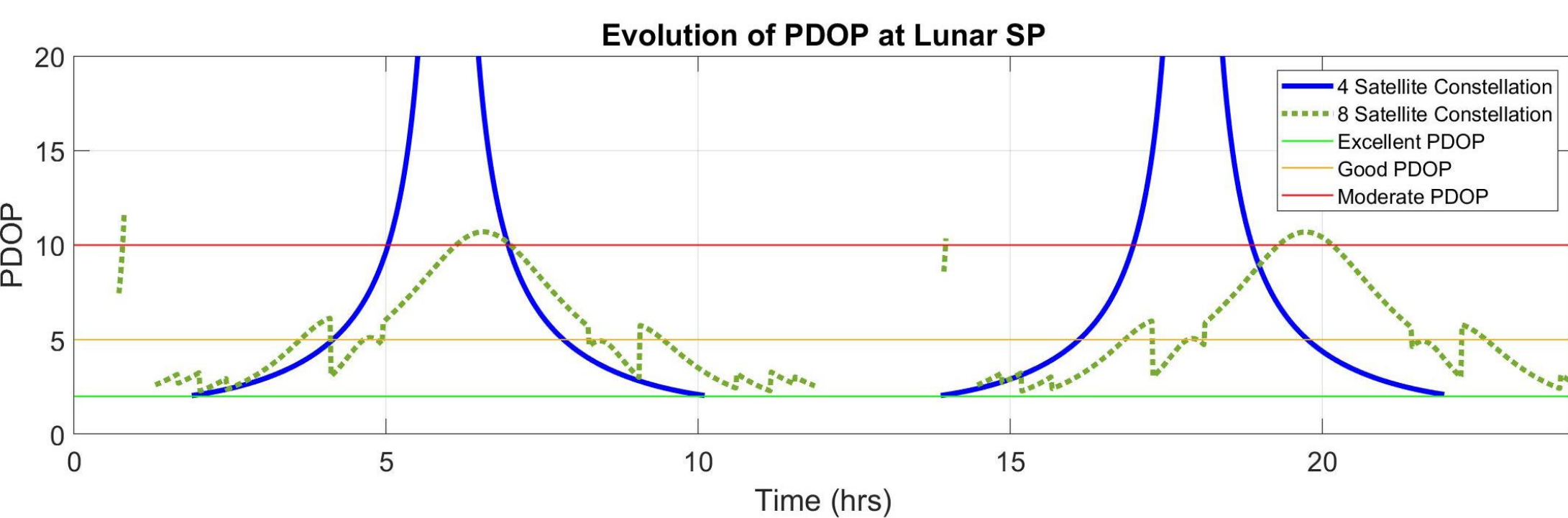


24-hour rover trajectory on Lunar South Pole

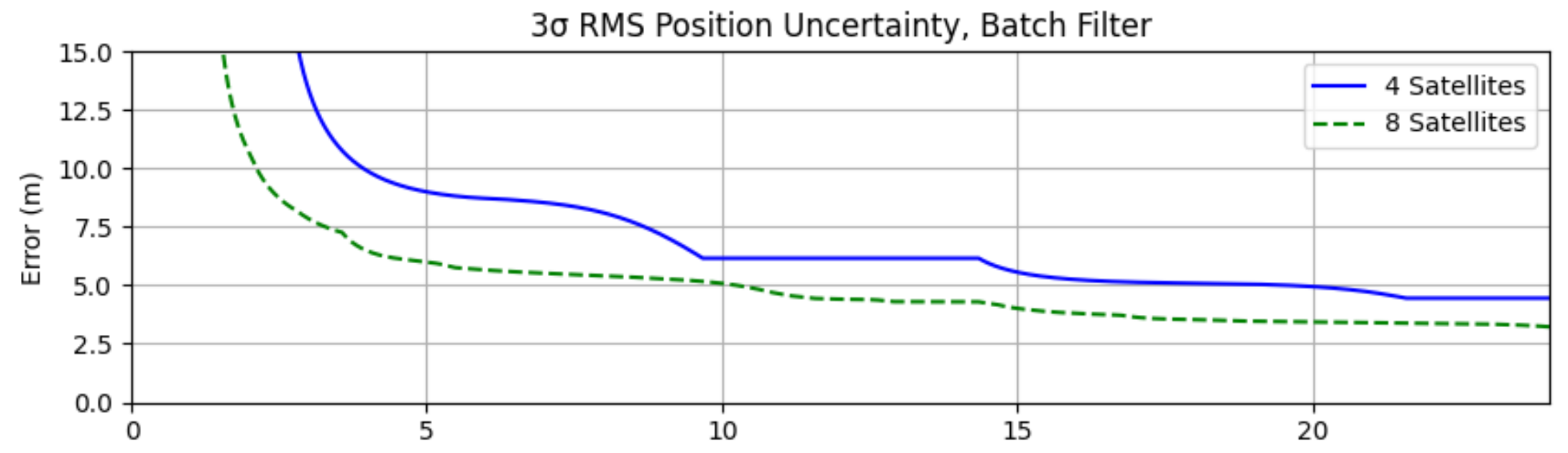
## III. Constellations from Literature



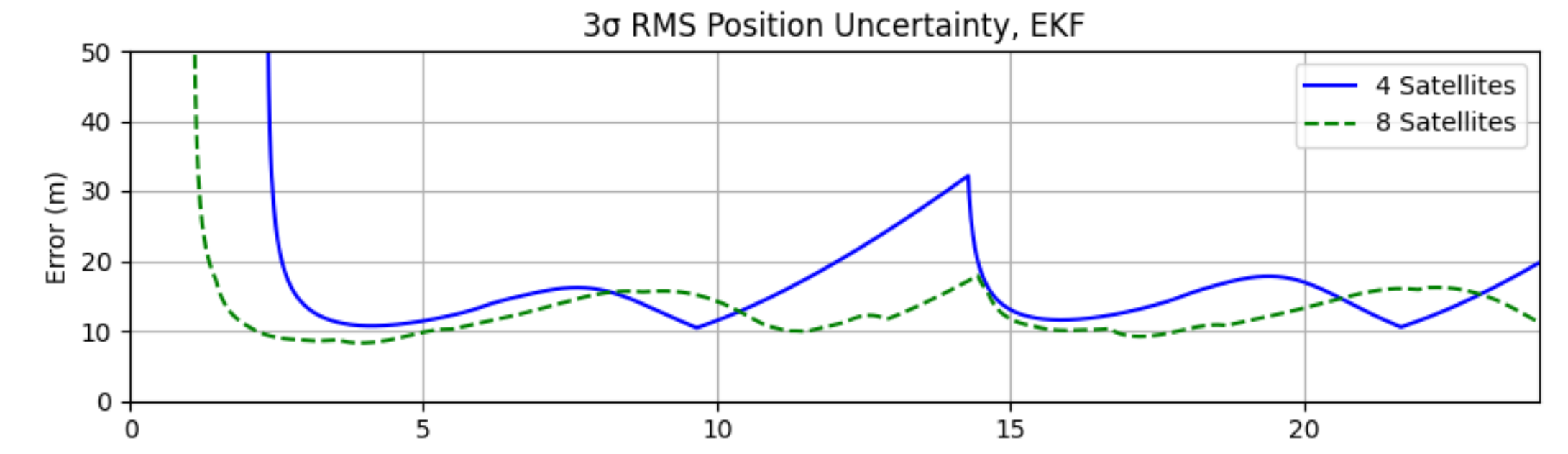
The 4 and 8 satellite constellations were derived from Bhamidipati Et al. [1] and Murata Et al. [2], respectively. Both utilize 2 mirrored orbits, with the major difference being the semimajor axis.



Periods in which there is no line denotes when there are not enough satellites in view for PDOP and thus a position fix to be obtained. Thresholds denote target PDOP levels.

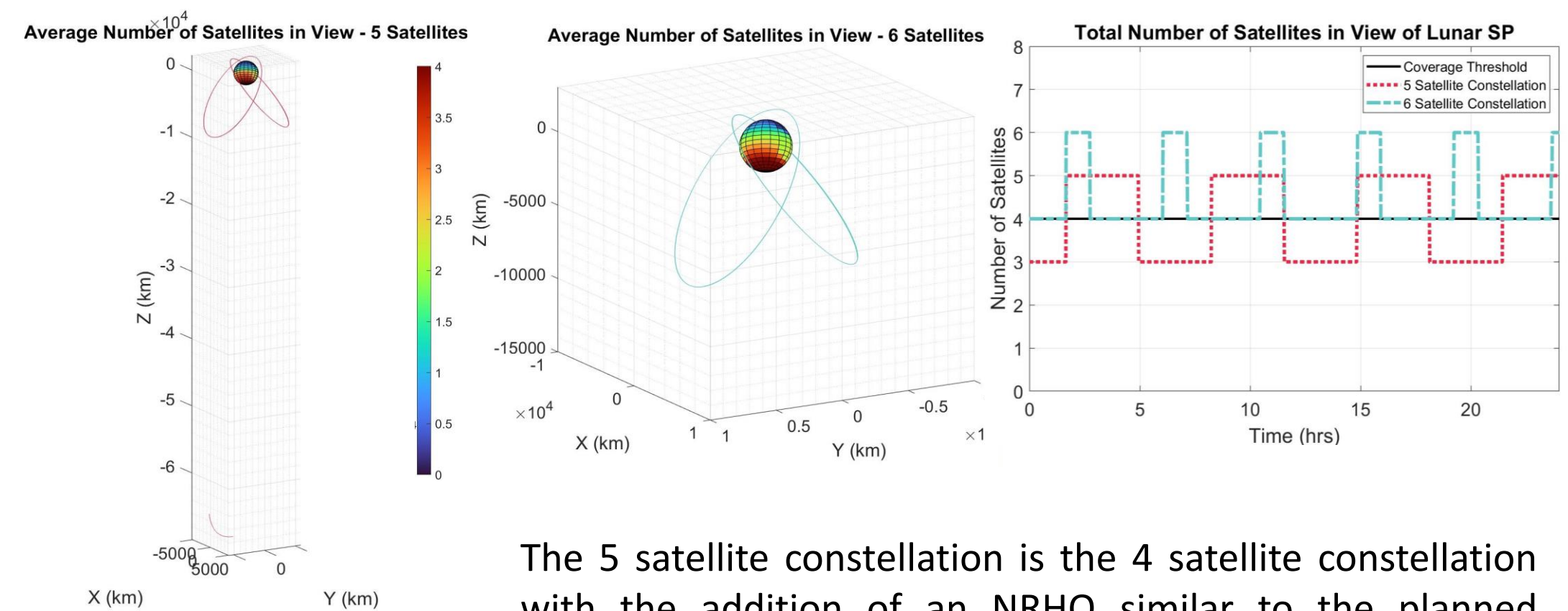


Accuracy for a ground station on the lunar surface batch filtering measurements using constellations from literature

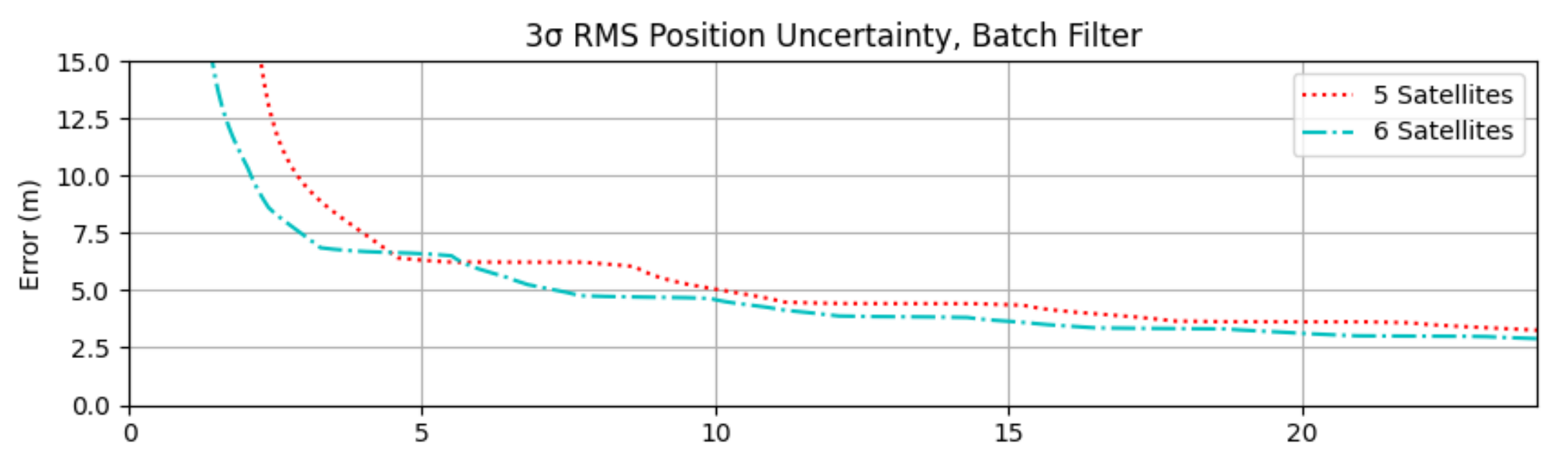
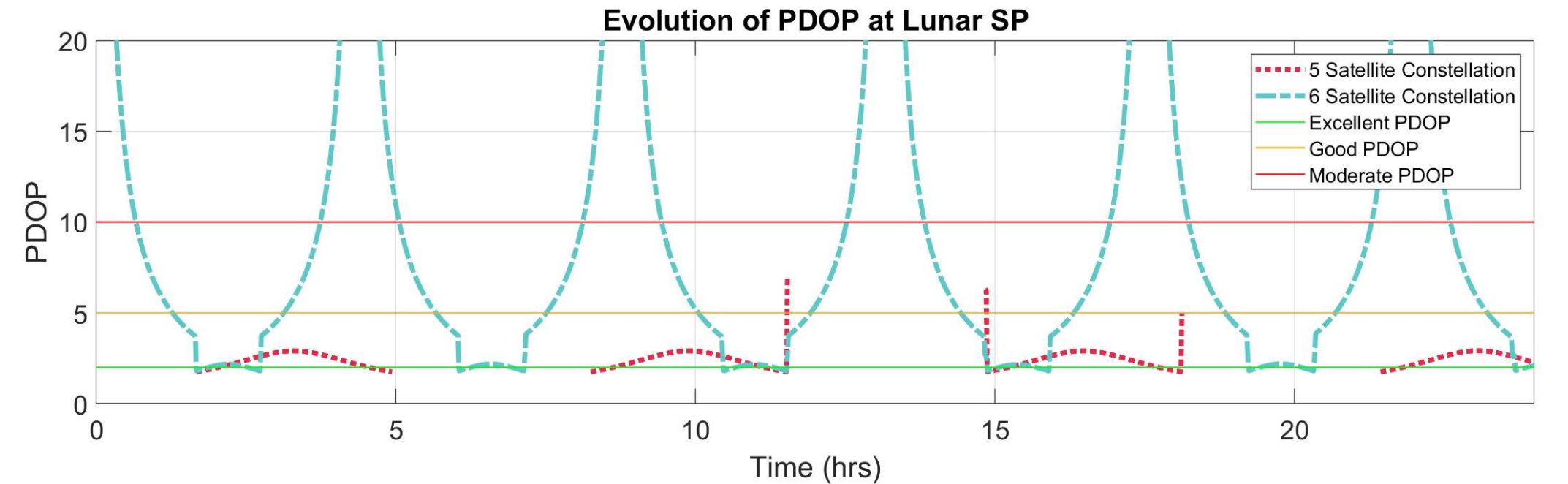


Accuracy for a rover on the lunar surface navigating using the constellations from literature in an EKF

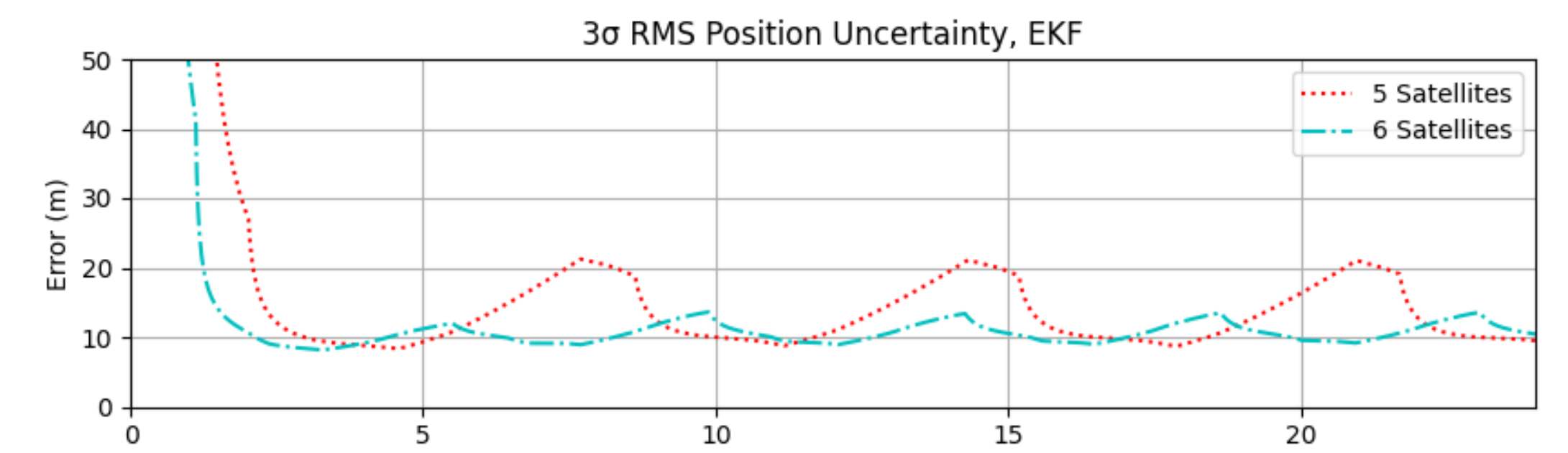
## IV. Novel Constellations



The 5 satellite constellation is the 4 satellite constellation with the addition of an NRHO similar to the planned trajectory of the Lunar Gateway. The 6 satellite constellation utilizes 2 mirrored orbits selected for increased coverage of the south pole.



Accuracy for a ground station on the lunar surface batch filtering measurements from new constellations



Accuracy for a rover on the lunar surface navigating using the new constellations discussed in an EKF

## VI. References

- [1] Bhamidipati, S., Mina, T., & Gao, G. "A case study analysis for designing a lunar navigation satellite system with time-transfer from earth-gps," In *Proceedings of the 2022 International Technical Meeting of The Institute of Navigation* (pp. 407-419).
- [2] Murata, M., Kawano, I., & Kogure, S. "Lunar navigation satellite system and positioning accuracy evaluation," In *Proceedings of the 2022 International Technical Meeting of The Institute of Navigation* (pp. 582-586).